THE EFFECTS OF HEAT TREATMENT ON THE PHYSICAL AND MECHANICAL PROPERTIES OF WHITE AFARA WOOD

(TERMINALIA SUPERBA)

The heat treatment of wood is an environmental friendly method for wood preservation. This process improves wood resistance to decay and its dimensional stability. In this study, the physical properties of White Afara wood*(Terminalia superb)* such as density, moisture content and shrinkage were investigated as well as mechanical property such as compression strength. Woods specimen that had been conditioned at 65% relative humility and 20 ± 2ºC temperature were subjected to heat treatment at (80, 100, 120, 140 and 160)ºC. Thereafter, at an optimum temperature 120^0C, the duration of heat treatment was varied for 2,4,6 and 8 hours for each specimen. In the course of this experiment, at 140^0C and 160^0C split along the grain of the wood specimen were observed, the colour of the wood becomes more darker and the wood becomes more brittle as temperature increases. Hence, the choice of 120^0C optimum temperature at 6 hours duration. The flash point of the experiment was determined at 180^0C. Due to its good weather resistance, White Afara wood when heat treated at120^0C optimum temperature is best suitable for outdoor applications such as external cladding, window frames and garden furniture.

CHAPTER ONE

1.0 INTRODUCTION

This chapter begins with an overview of wood in Nigeria, the need to study the heat treatment of Nigerian woods, the significance of the study, the aim and objectives of this research and the limitations .

1.1 Overview **of wood in Nigeria**

Wood in the Nigerian society can be broadly classified as hardwood and softwood. Hardwood is derived from angiosperm or broad-leaved trees such as Afara *(Terminalia superba)* and Danta *(Nesogordonia papaverifera)*.Softwood is obtained from coniferous trees, which have needle-like leaves such as Araba *(Ceiba pentadra)* and Obeche *(Triplochiton scleroxylon)*.Wood, from time immemorial has established itself as a substantial material for variety of applications, such as constructions of building, furniture items, bridges, boats, ships, lorry and tractor wagons and aircraft carrier (Fuwape 2000). Indeed, one of the first major innovations of mankind was utilizing fire, fueled by wood, for cooking and heating. Since this ancient beginning, the uses of wood, and the value of the forest, have expanded dramatically, as the population of humans and their economies grew. Other important products that forests provided were food, in the form of berries, nuts, fruits, and wild animals (Christopher 2005).Furthermore, wood was the most important material in early human economies, and though other materials have grown in importance, wood used for solid products, fibre, and chemicals is still the largest single type of raw material input by weight (Haynes 2003).Today, wood is still being used in tools, paper, buildings, bridges, guardrails, railroad ties, posts, poles, mulches, furniture, packaging, and thousands of other products. According to Keay (1964), Nigerian forests are naturally blessed with over nine hundred different species of trees which are main sources of timber products. The abundant availability of these trees in Nigeria is attributed to prolonged rainy season, resulting in high annual rainfall (above 2000milimetres), which ensures adequate supply of water and promotes perennial tree growth.

1.2 The need to study the heat treatment of Nigerian woods

A survey of the available literature and journals as well as research activities carried out at various forest research institutes in Nigeria such as Forest Research Institute of Nigeria (FRIN) Ibadan and Engineering Materials Institute (EMDI) Akure revealed no information on the effect of heat treatment on wood in Nigeria

1.3 The Significance of the Study

To provide forest managers, woodworkers, and wood designers adequate information required on the heat treatment of White Afara wood *(Terminalia superba)* for various applications that require specific qualities. Also, to provide improved information to the wood using industries about characteristics of heat treated woods for future timber supplies, thus, to make strategic processing and investment decisions

1.4 Aim and Objectives of the research work

The aim of this research is to determine the optimum processing temperature of white Afara wood *(Terminalia superba).* Moreso, to recommed White Afara wood *(Terminalia superba)* for suitable technological applications for industrial uses.

1.5 Limitations to the study

Only some few physical and mechanical properties of White Afarfa wood *(Terminalia superba)* were tested due to limited testing equipment. In addition due to huge cost of purchasing, sawing, machining and experimenting on the woods, Samples for this test were only taken from the middle log

1.6 Thesis outlines

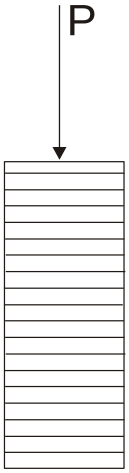
Chapter One contains an introduction to the thesis, overview of wood in Nigeria, the need to study the heat treatment of Nigerian woods, the significance of this study, aim and objectives of this research and the limitations. Chapter Two evaluated the physical properties such as density, moisture content and shrinkage as well as mechanical property, compression strength, grain directions and strength of wood, wood microstructure, wood processing, wood conservation and utilization, wood seasoning, classification of timber for drying, and methods of drying timber. Chapter Three discuss the material and methods used to obtained the desired results. Chapter Four presents the result and discussion while Chapter Five covers the conclusion and recommendations.

CHAPTER TWO

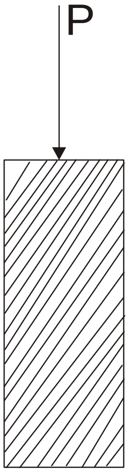
2.0 REVIEW OF RELATED LITERATURE

In order to provide insight into the behavior of wood during processing and service conditions, this chapter evaluated the physical properties such as density, moisture content and shrinkage as well as mechanical property, compression strength, wood strength, wood microstructure, wood processing, wood conversion and utilization, wood seasoning and method of drying timber.

2.1 Grain directions and strength of wood



(Figure 2.1)



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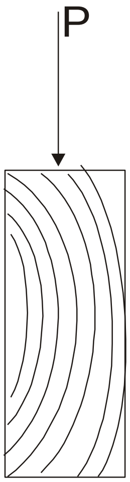

(Figure 2.3)

Figure 2.1: The directions of load to direction of annual growth rings, during perpendicular cut to the grain direction or 90^{o}. Figure 2.2: 45^{o}. Figure 2.3: parallel cut to the grain direction. or 0^{o}.
Source: (Wood handbook, 1999).

Wood is a natural polymer (parallel strands of cellulose fibres) held together by a lignin binder (Engler, 2009).These long chains of fibres make the wood exceptionally strong.They resist stress and spread the load over the length of the board. Furthermore, cellulose is tougher than lignin. In order to take full advantage of woods strength, full attention must be given to the grain directions. It is easier to split a board with the grain (separating the lignin) than it is easy to break across the grain (separating the cellulose fibre). Hence, when you lay out a parts of a project, always orient the grain so that the fibre support the load. Whenever possible, cut the parts so the grain is continuous running the length of the board. This also applies to wood joinery. When cutting a tenon, the wood grain must run the length of the tenon and the board so the grain is continuous.

2.2.0 Physical Properties

Shrinkage, density and moisture content were the physical properties examined in this chapter.

2.2.1 Shrinkage

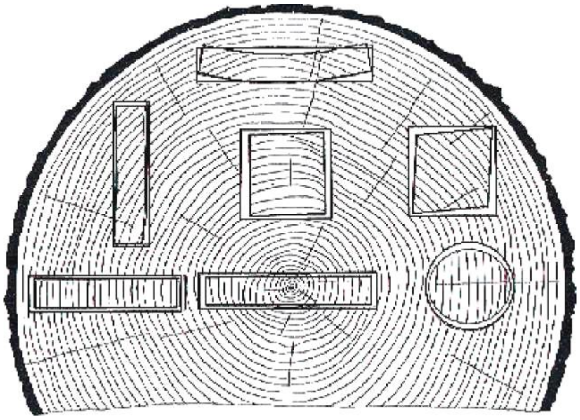

Figure 2.4: Shrinkage and distortion of wood upon drying

(Source: Simpson and TenWolde, 1999).

Wood is dimensionally stable above the fibre saturation point but below that point, wood shrinks or swells due to loss or gain of bound water from the cell walls. This movement is greatest in the direction of the annual growth rings (tangential), about one half as much across the rings (radially), and much less along the grain (longitudinally). The total amount of shrinkage that occurs in one of these three directions from the green to ovendry condition is typically expressed as a percentage of the green dimension. This shrinkage varies considerably from species to species. Wood undergoes about 8% tangential shrinkage, 4% radial shrinkage, and 0.1% longitudinal shrinkage from the green to ovendry condition (Kovalick, 2012). Heavier (denser) wood generally shrinks more than lighter woods. The practical implication of all this to woodworker is to make provisions for wood movement, especially across the widths of board. Most boards are flat –sawn which results in the board faces running tangentially to the growth rings of the tree. Quarter sawn boards are much more dimensionally stable across their width because the growth rings are oriented at right angles to the board faces. They will experience greater moisture- related movement in thickness than flat-sawn boards, but this movement is often negligible because boards are generally much wider than they are thick. The major types of distortion as a result of these effects are illustrated in Figure 2.4 above.

2.2.2 Moisture content of wood

The moisture content of wood is defined as the weight of water in wood given as a percentage of ovendry weight. Moisture exists in wood either as bound water that is held chemically within the cell walls or as free water that is stored in the cell cavities. As freshly cut green wood dries, the free water evaporates first. The fibre Saturation point is reached when all the free water is gone, leaving only the bound water within the cell walls. The fibre saturation point average about 28 % moisture content. When the moisture content drops below the saturation point, the wood will begin to shrink and undergoes changes in its physical aand mechanical properties (notably becoming stronger). The moisture content of wood fluctuates in response to changes in the relative humidity of its environment. As the relative humidity increases and the wood expands in size; if the relative humidity drops, the amount of boundwater in the wood decreases and the wood shrinks, (these dimensional changes are basically caused by swelling and shrinking of the individual wood cells). The equilibrium moisture content (EMC) is reached when wood is no longer gaining or loosing moisture. It has reached an equilibrium with its environment. Temperature also plays a role here for a given relative humidity, the equilibrium moisture content of a given wood will decreased as temperature increases. Wood that as been stored outside and then brought into the shop should be given time to adjust to the shop environment before been cut or otherwise machined. Failure to allow the wood to reach an equilibrium moisture content in the shop will invite warpage and other shrinkage related problems.

2.2.3 Density

The density of wood is the weight per unit volume usually expressed in kilogramme per cubic metre or grammes per cubic centimetre at a specified moisture content. Density is the single most important indicator of strength in wood. A wood that is heavier, will generally tend to be stronger than light one. In engineering design wood density is associated with fast growth because of cheap volumetric construction costs, high density is associated with the survival because of biomechanical and hydraulic safety.

2.2.4 Wood Strength

Strength may be defined as the ability to resist applied stress. The greater the resistance, the stronger the material. Resistance may be measured in several ways. One is the maximum stress that the material can endure before failure occurs. Another approach is to measure the deformation or strain that results from the given level of stress before the point of total failure.

2.2.5 Compression Strength

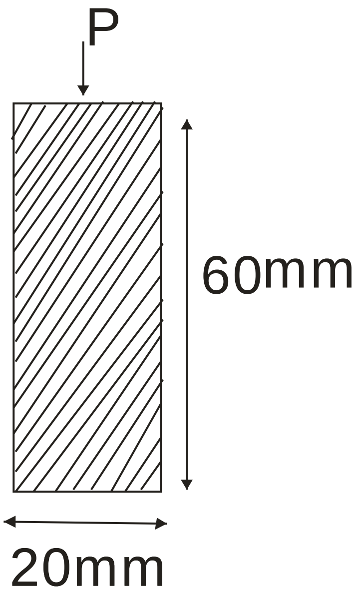

Figure 2.5: Applications of load during compression test parallel to the grain.

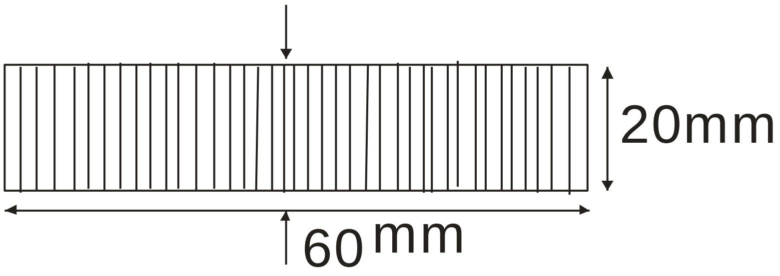

Figure2.6:Aplication of load during compression test perpendicular to the grain

Compression strength is the stress sustained by a board when pressure is applied parallel to the grain. In design, the woodworker primarily consider two types of compression strength. Compression strength parallel to the grain and compression strength perpendicular to the grain. Compression parallel to the grain shortens the fibres in the wood lengthwise. An example would be chair and table or a table legs which are primarily subjected to downward rather than lateral pressure. Wood is very strong in compression parallel to the grain and this is seldom a limiting factor in furniture design. It is considerably weaker in compression perpendicular to the grain. An example of this type of compression would be the pressure that chair legs exert on a wooden floor. If the applied pressure (weight) exceed the fibre stress at proportional limit for the wood, permanent indentations will result in the floor. Compression strength is measured in Mega Pascal.

2.2.6 Wood Microstructure.

The different between softwood and hardwood is found in the microscopic structure of the wood. Softwood contains only two types of cells: longitudinal wood fibres (tracheids) and transverse ray cells. Hardwood have vessel elements for water transportation that softwood lacks, these vessel elements are evident in hardwood as pores. In softwood water transportation within the tree is via the tracheid only. The arrangement of pores has an enormous effect on the grain. Ring porous hardwoods have a pronounced or strong grain pattern of ring diffuse stock is much less distinct. Hardwood pores also come in a wide range of sizes. Woods with large pores that are easily visible to the naked eye are said to have open grain. Those with smaller pores, too small to see clearly, have a closed-grain woods because the surface is not smooth. When the wood is sawn and pores are splits, the open pores create tiny valleys and rifts**.**

2.3.0 Wood Processing

Wood processing is an engineering discipline comprising the production of forest products, such as pulp and paper, construction materials, and tall oil. Wood processing produces additives for further processing of timber, wood chips cellulose and other prefabricated material. (www.edro.com/general/guarantee.htm).

2.3.1 Wood Conversion and Utilisation

Conversion of wood is the altering of log or tree to create planks, timbers, or other desired elements. Trees are extracted from the forest in forms of logs or billets. These logs and billets are converted into utilisable products through either mechanical, chemical, thermal or thermo-chemical processes (Fuwape 2000). The mechanical processing technique is the most common method of converting wood to utilisable products. This may be by using simple hand tools or complex network of computerised machines. The wood-based factories that adopt mechanical processing techniques include sawmills, veneer mills, plywood mills and particleboard mills. Pulping of wood by the use of either sulphite, kraft, semi-chemical or chemi-mechanical process constitutes the major chemical method of converting wood to utilisable products. The chemical pulps are subsequently converted into paper products. Wood may also be thermally or thermo chemically converted to charcoal, pyrogas, pyro-oil and complex chemical derivatives. The conversion of wood is through tangential or radial splitting of the log, it can then be worked further to create the desired end product. There are three main methods of converting timber, plain or crown sawn, quarter sawn and rift sawn.

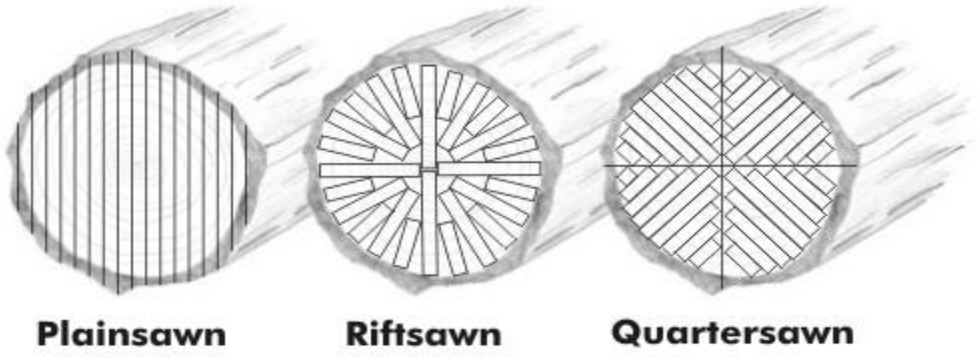

Figure 2.7: Plainsawn, Riftsawn, and Quartersawn (http://www.edroman.com/customshop/htm)

2.3.2 Plain Sawn

This is also known as through and through method which produces mostly tangentially sawn timber and some quarter sawn stuff. Plain sawn (flat-sawn) lumber has the growth rings of the tree parallel to the board's broad face. Plain sawn wood highlights the grain, loops and growth swirls of the wood. Plain sawn lumber has growth rings that are less than 30^o.

2.3.3 Quarter Sawn

Quarter sawn has the growth rings of the tree approximately perpendicular to the board's surface. It is far more expensive than plain sawn because of the need to double handle the log. There is also more wastage. It is however more decorative and less prone to cup or distort. Quarter sawn wood has the straightest grain, and is used for necks, fingerboards or anyplace where strength and stability is a must. It is much more expensive to use quartersawn wood because you need bigger trees to get wood that will be appropriate. By definition, quartered sawn lumber produces lumber where by the growth rings are positioned at a 60° to 90° angle. 98% of the lumber produced in the world in plain sawn, which may make quartered sawn lumber mills seem small; the most obvious characteristic of quartersawn lumber is the type of grain pattern produced. By quartersawing, the saw actually splits the medullary ray, causing the ray to appear shiny or reflective. Appearance is not the only reason why quartersawn is sought after, quartersawn wood:

Does not shrink or swell in width

Reduces twisting, warping and cup

Wears less in almost all applications

Does not surface check or split

2.3.4 Rift Sawn

Rift sawn lumber is cut at a 30 degree or greater angle to the growth rings. This produces narrow boards with accentuated vertical or straight grain patterns. The rift board does not have shiny characteristic. It does produce vertical grain - usually used in a more contemporary setting specified by architects.

2.3.5 Wood Seasoning

Wood seasoning (drying) may be described as the art of ensuring that gross dimensional changes through shrinkage are confined to the drying process. Ideally, wood is dried to that equilibrium moisture content as will later (in service) be attained by the wood. Thus, further dimensional change will be kept to a minimum. Drying, if carried out promptly after felling of trees, also protects timber against primary decay, fungal stain and attack by certain kinds of insects. Organisms, which cause decay and stain, generally cannot thrive in timber with moisture content below 20%. Several, though not all, insect pests can live only in green timber. Dried wood is less susceptible to decay than green wood as the moisture content in green wood is generally above 20%. Other advantages of drying timber are according to Walker et al., (1996) are:

Dried timber is lighter, and the transportation and handling costs are reduced.

Timber for impregnation with preservatives has to be properly dried if proper penetration is to be accomplished, particularly in the case of oil-type preservatives.

In the field of chemical modification of wood and wood products, the material should be dried to certain moisture content for the appropriate reactions to occur.

Dry wood generally works machines, finishes and glues better than green timber. Paints and finishes last longer on dry timber.

The electrical and thermal insulation properties of wood are improved by drying.

Prompt drying of wood immediately after felling therefore significantly upgrades and adds value to raw timber. Drying enables substantial long-term economy by rationalizing the use of timber resources.

2.6.0 Classification of Timbers for Drying

Timbers are classified as follows according to their ease of drying and their proneness to drying degrades:

2.6.1 Highly refractory woods

These woods are slow and difficult to dry if the final product is to be free from defects, particularly cracks and splits. Example is heavy structural timbers with high density such as ironbark *(Eucalyptus Paniculata)*. It requires considerable protection and care against rapid drying condition for the best results (Bootle 1994).

2.6.2 Moderately refractory woods

These timbers show a moderate tendency to crack and split during seasoning. They can be seasoned free from defects with moderately rapid drying conditions. Example is Sydney blue gum *(E.saligna)* which is potentially suitable for furniture.

2.6.3 Non-refractory woods

These woods can be rapidly seasoned to be free from defects even by applying high temperatures (dry-bulb temperatures of more than 100 ° C) in industrial kilns. Example is softwood such as Pinus Radiata.

2.7.0 Methods of Drying Timber

Broadly, there are two methods by which timber can be dried:

(i) Natural drying or air drying (ii) Artificial drying.

2.7.1 Air Drying

Air drying is the drying of timber by exposing it to the air. The technique of air drying consists mainly of making a stack of sawn timber on raised foundation in a clean, cool, dry and shady place. Rate of drying largely depends on climatic conditions, and on the air movement. For successful air drying, a continuous and uniform flow of air throughout the pile of the timber needs to be arranged (Desch and Dinwoodie 1996). The rate of loss of moisture can be controlled by coating the planks with any substance that is relatively impermeable to moisture; ordinary mineral oil is usually quite effective. Coating the ends of logs with oil or thick paint, improves their quality upon drying. Air drying often produces a higher quality, more easily workable wood than with kiln drying, however, depending on the climate; it takes several months to a number of years to air-dry wood.

2.7.2 Kiln Drying

The process of kiln drying consists basically of introducing heat. This may be directly, using natural gas and electricity or indirectly, through steam-heated heat exchangers, although solar energy is also possible. In the process, deliberate control of temperature, relative humidity and air circulation is provided to give conditions at various stages of drying the timber to achieve effective drying. The timber is stacked in chambers, called wood drying kilns, which are fitted with equipment for manipulation and control of the temperature and the relative humidity of the drying air and its circulation rate through the timber stack (Walker *et al.*, 1993). Kiln drying provides a means of overcoming the limitation imposed by erratic weather conditions. In kiln drying as in air drying, unsaturated air is used as the drying medium. Almost all commercial timbers of the world are dried in industrial kilns.

2.8.0 Review of previous research

A search through other literatures outside Nigeria, revealed that many studies have been performed on the physical and mechanical properties of wood in order to improve its dimensional stability. Kol (2010), studied the mechanical and physical properties of two Turkish wood species, Pine (*Pinus Nigra Arnold*) and Fir (*Abies Bornmulleriama*). Both Pine and Fir woods were subjected to thermal modification for 2 hours at 212^0C and 190^0C respectively. The results indicated that heat treatment clearly decreased all the physical and mechanical properties tested such as compression strength, tensile strength and modulus of rupture. Also, Murat *et al.*, (2009), examined the effects of heat treatment on the mechanical properties of Scotch pine (*Pinus sylvestris*) and Chest nut (*castanea sativa*). Wooden samples were kept at temperatures of 100, 150 and 200^0C for times of 6,4 and 2 hours respectively. The results showed that mechanical properties such as modulus of rupture, impact bending strength and compression strength decreased with increase in temperature. In 2012, Mehmet *et al.*, reported a decrease in equilibrium moisture content of Oak *(Quercus petraea)* when the wooden samples were subjected to temperature of 200^0C for 2 hours. Furthermore, in 2009, Korkut recorded a decrease in density of Hornbeam *(Carpinus betulus)* when wood samples were treated at 180^0C for 6 hours.

CHAPTER THREE

3.0 MATERIALS AND METHODS

This chapter evaluates the equipment, materials and methods used to carry out this research.

3.1 Data collection and Sample selection.

Ala forest reserve about 8 kilometres from Akure, is home to several species of useful softwoods and hardwoods. The White Afara wood (*Terminalia Superba)* used for this research was found in this reserve. After felling and sawing a total of seven sound planks were obtained from the middle log 2 metres in girth. The planks obtained from the middle log were machined into the various standard dimensions (British Standard 373, American Society for Testing and Materials D143-94, D4761-02) using a circular machine. The wood pieces were sawn with the annual rings at 45° to the surface so that the deformation would be smaller. This ensured the hardness of the surface would be stronger and the general outlook after heat treatment would be better. Only defect free samples were used for these tests. Three samples each were considered for untreated and treated. Preliminary test were first conducted to determine the flash point. Treated samples were subjected to heat treatment at (80,100,120,140 and 160)ºC. At 140ºC splits along the grain was observed. Further heating at 160ºC, the split become more pronounced. Hence, the choice of an optimum temperature 120ºC. Similarly, at an optimum ovendry temperature 120ºC samples were set for 2, 4, 6 and 8 hours. Split along the grain was also observed at 8 hours before the wood burn at 10 hours. Treated samples were kept in a desicator for three days to stabilise the relative humidity of the wood.

3.2 Anatomical Properties

In other to determine the microscopic features of White Afara wood (*Terminalia Superba)* the following procedures were adopted:

3.2.1 Sample preparation

Standard rectangular sample 20x20x60 millimetre was prepared according to ASTM D143-94 from the core middle wood.

3.2.2 Softening.

Softening was done in other to get the uniformly thin section needed by boiling the wood sample in water for 48 hours at a temperature above 100ºC.

3.2.3 Sharpening of Microtome Knife.

Two knives were used to cut the sections needed for sharp cuttings, as one knife was used the other was sharpened.

3.2.4 Cutting

The knife was allowed to travel parallel to the side of the block in cutting section when a thin section of about 10 microns was tightened to an apartment in the microtome. Methylated spirits were used to moisten the block.

3.2.5 Staining.

Staining was done to bring out the different anatomical features of importance under study dehydration. This was done by stocking the section left in the disc with a sample of safranin in water. Accelerated dehydration process was done by adding moderate quantity of 95% ethanol which was allowed to stay for about 50 seconds.

3.2.6 Moistening.

This was done to prevent rolling, coiling and drying of the section by adding a clove oil to the section in the Petri dish .

3.2.7 Mounting.

Forceps was used to trim into smaller sizes each section. Thereafter, a thin Canada basalm was laid across the section and a cover slip was placed over the section. Slightly warming of the section was done to expel all air bubbles.

3.2.8 Labelling.

Each specimen was labeled initially with a wax pencil before it was labelled permanently on the slide. Pictures were taken at (10x magnification) at the radial and tangential sections using an optical microscope.

3.3 Density Determination

Rectangular wood blocks (20x20x60) millimetres were cut into standard dimensions according to ASTM D143-94 oven temperature at (80, 100, 120, 140 and 160) ºC for 6 hours and all the samples used for density were dried to constant weight. Thereafter samples were heat treated for 2, 4, 6 and 8 hours at constant temperature 120ºC. the weights and dimensions of all the wood samples were taken and recorded using a digital metter weighing balance. Density was then calculated as the weight density instead of mass as:

$$\textbf{Wt density} = \frac{weight\ of\ wood\ with\ moisture}{volume\ of\ wood\ with\ moisture} \qquad (3.1)$$

Source: Simpson and TenWolde, 1999

3.4 Percentage Moisture Content

Samples used for moisture content were cut into standard rectangle according to ASTM D143-94. The digital weighing balance was use to take the initial and final weights. Oven temperatures were set at (80, 100, 120, 140 and 160)ºC ± 2ºC for 6 hours. Subsequently, at

120ºC durations were varied at 2, 4, 6 and 8 hours. Moisture contents were then calculated as:

$$MC = \frac{Moist\ Weight - Dry\ Weight}{Dry\ Weight} X100\% \qquad (3.2)$$

Source: Simpson and TenWolde, 1999

3.5 Percentage Shrinkage

Wood samples used for shrinkage were cut to standard according to ASTM D1430-94. The tranverse sections of the wood samples were observed with the aid of the hand lens to determine the directions of the wood rays. Parallel cuts on the rays give the radial direction while perpendicular cuts on the rays give the tangential directions. Initial dimentions were taken at the radial and tangential directions marked (R) and (T) with a digital vernier caliper before oven drying at (80, 100, 120, 140 and 160)ºC for 6 hours. Subsequently, at 120ºC durations were set at 2, 4, 6 and 8 hours.

Percentage shrinkage was calculated as:

$$\textbf{Shrinkage (percent)} = \left(\frac{wet\ dimension - dry\ dimension}{wet\ dimension}\right) X\mathbf{100} \qquad (3.3)$$

Source: Simpson and TenWolde, 1999

Volumetric Shrinkage = (Radial Shrinkage + Tangential Shrinkage) (3.4)

Source : (Dinwoodie, 1981)

3.6 Compression Test

Standard rectangular dimension of the wood samples used for compression test were cut at (20x20x60) millimetres according to ASTM D4761-02 standard test method for mechanical properties of lumber and wood based structural materials. Each standard samples was placed in between two dies under a pre- determined load of 2000 kilogrammes in an Hounsfield Tensometer. Load was applied at the rate of 0.01 millimetre per second and the corresponding force at the point of failure was taken directly on the scale till the point where the mercury that measures the level of the structure failed. Compression strength was obtained by dividing the load at failure by the cross sectional areas:

$$ŕ = \Omega/Ą \tag{3.3}$$

(Source: Record, 1914)

where $ŕ$ represents the compression strength, Ω represents the applied load and $Ą$ represents the cross-sectional area of the specimen.

CHAPTER FOUR

4.0 RESULTS AND DISCUSSION

The results at the various physical and mechanical properties of White Afara wood (*Terminalia superba*),is presented in this chapter. It begins with the anatomical features and its discussion

4.1 Microscopic features and functions

White Afara wood (*Terminalia superba*) was examined at the unprocessed state to determine if the wood is an hardwood or softwood. The tangential section of a typical White Afara wood (*Terminalia superba*) are the vessel element in various sizes (Ve), the axial parenchyma cells (Ce) and the various elements of various kinds. At the radial sections is the rays (Rays) with ray parenchyma cells (Pa). the vessels of a typical White Afara wood (*Terminalia superba*) are rings porous and ranges from medium to large. It average between 200 to 300 micrometre. Individual vessel element occurs in a solitary form.simply perforation plate occurs between the vessel element. It is also a single vessel element because it is wider than tall and open on both ends. The main function of the vessel element is for water conduction. The fibre (F) functions solely as support. The axial parenchyma cells present are essentially of the same size and shape. The ray parenchyma cells that occur ar the radial section are procumbente and homocellular in shape and size. They are larger radially than they are tall.

4.2 Physical and mechanical properties

Table 4.1: Moisture Content (MC) of White Afara wood (*Terminalia superba*) varying temperature at 6 hours.

Temperature(^{0}C)	Test 1 (%)	Test 2 (%)	Test 3 (%)	Average (%)
Unprocessed	9.12	17.9	12.15	13.06
80	8.70	15.63	11.20	11.84

100	13.23	4.25	14.06	10.51
120	8.76	11.83	4.19	8.26
140	5.87	7.90	6.03	6.60
160	7.33	9.89	1.09	6.10

Table 4.2 : Moisture Content (MC) of White Afara wood *(Terminalia superba)* varying time at 120^{0}C

Time (hours)	Test 1 (%)	Test 2 (%)	Test 3 (%)	Average (%)
2	11.50	10.93	9.66	10.70
4	8.71	12.55	6.63	9.30
6	8.75	12.10	4.46	8.44
8	8.94	10.09	4.11	7.71

Table 4.1 The lowest moisture content value obtained from table 4.1 above was 6.10%. total loss when compared to the control was 53.29%. at $p < 0.05$ confidence level, ANOVA test (Appendix A, Table 1) shows no significant difference. Also, from the relationship between the moisture content between the White Afara wood (*Terminalia superba*) and processing time the ANOVA (Appendix B, Table 1) shows no significant difference at $p < 0.05$ confidence level. Mehmet *et al.*(2012), reported that heat treatment resulted in decreased in the equilibrium moisture performances, darkened colour and increase dimensional stability of Oak (Quercus petraea). The equilibrium moisture content decreased up to 8.13% when compared with untreated wood.

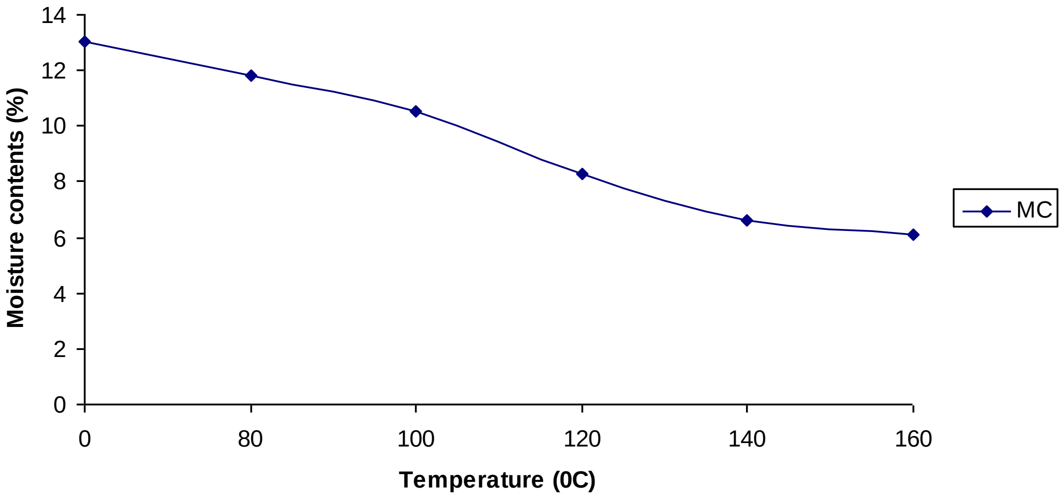

Figure 4.1: The relationship between the Moisture Content of White Afara wood (*Teminalia superba*) and the processing temperature.

From Figure 4.1 above, the highest moisture content of White Afara wood (*Terminalia superb*) was at 80^{0}C, while the greatest reduction in moisture content occurred between 100ºC and 120ºC. Subsequent reduction in moisture content was found to be less than that obtain between 100ºC and 120ºC. the lowest moisture content was observed at 160ºC.

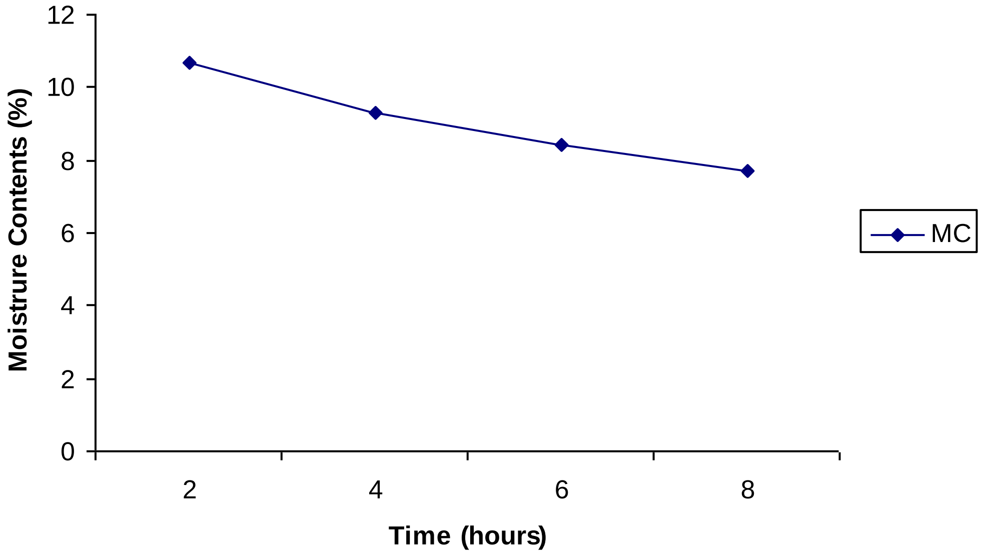

Figure 4.2: The relationship between the Moisture Content of White Afara wood (*Terminalia superba*) and the processing time.

It is evident from Figure 4.2 above that the highest moisture content was observed at 2 hours while the lowest moisture content was at 8 hours. The greatest reduction occurs between 4 to 6 hours while subsequent reduction was found to be less than that obtained between 4 to 6 hours.

Table 4.3: Compression Strength Perpendicular to the grain of White Afara wood (*Terminalia superba)* varying Temperature at 6 hours.

Temperature (^oC)	Test 1(MPa)	Test 2 (MPa)	Test 3 (MPa)	Average (MPa)
Unprocessed	7.46	7.42	8.27	7.72
80	7.48	7.35	7.33	7.39
100	7.27	7.42	7.32	7.34
120	7.35	7.24	7.18	7.26
140	7.15	7.25	7.11	7.17
160	7.01	7.16	7.04	7.07

Table 4.4: Compression Strength Perpendicular to the grain of White Afara wood *(Terminalia superba)* varying time at 120^0C.

Time (hours)	Test 1 (MPa)	Test 2 (MPa)	Test 3 (MPa)	Average (MPa)
2	7.35	7.23	7.24	7.27
4	7.16	7.32	7.21	7.23
6	7.19	7.13	7.29	7.20
8	7.14	7.24	7.08	7.15

From Table 4.3 above the lowest Compression Strength Perpendicular to the grain was was 7.07 Mega Pascal.8.42% was the total loss obtained when the control value was compared with the treated value. At p<0.05 confidence level, ANOVA test shows significance difference. Also, from the follow up test Duncan's Multiple range test (Appendix A, Table 3) shows the level of significance at p<0.05 confidence level. Yildiz (2002), reported that the compression strength perpendicular to the grain observed for Beech (Fagus orientalis) decreased by 36% when compared to the control value at 200ºC for 6 hours.

Table 4.5: Compression Strength parallel to the grain of White Afara wood (*Terminalia superba)* varying temperature at 6 hours.

Temperature (^{0}C)	Test 1 (MPa)	Test 2 (MPa)	Test 3 (MPa)	Average (MPa)
Unprocessed	21.0	25.0	19.9	21.96
80	24.0	19.60	21.13	21.56
100	20.95	24.30	19.20	21.48
120	21.25	17.45	18.30	19.0
140	16.98	14.75	19.70	17.14
160	18.20	12.30	12.80	14.43

Table 4.6: Compression Strength Parallel to the grain of White Afara wood *(Terminalia superba)* varying time at 120^0C.

Time (hours)	Test 1 (MPa)	Test 2 (MPa)	Test 3 (MPa)	Average (MPa)
2	22.6	22.0	17.9	20.83
4	21.9	17.4	19.5	19.60
6	18.4	21.5	18.2	19.37
8	18.5	20.7	18.3	19.17

14.93 Mega Pascal was the lowest value obtained from Table 4.5 above. Total loss compared to the control was 34.29%. at $p<0.05$ and $p>0.05$ confidence level from ANOVA and Duncan's multiple range test (Appendix A, Table 4,5) show that all differences were statistically significant. Moreso, from (Appendix B, Table 3) from the relationship between compression strength parallel to the grain and the processing time shows no significance differences at $p<0.05$. Korkut *et al.*, (2009) reported a decreased by 30% for Hornbeam (Carpinus betulus) when treated at 170ºC for 8 hours.

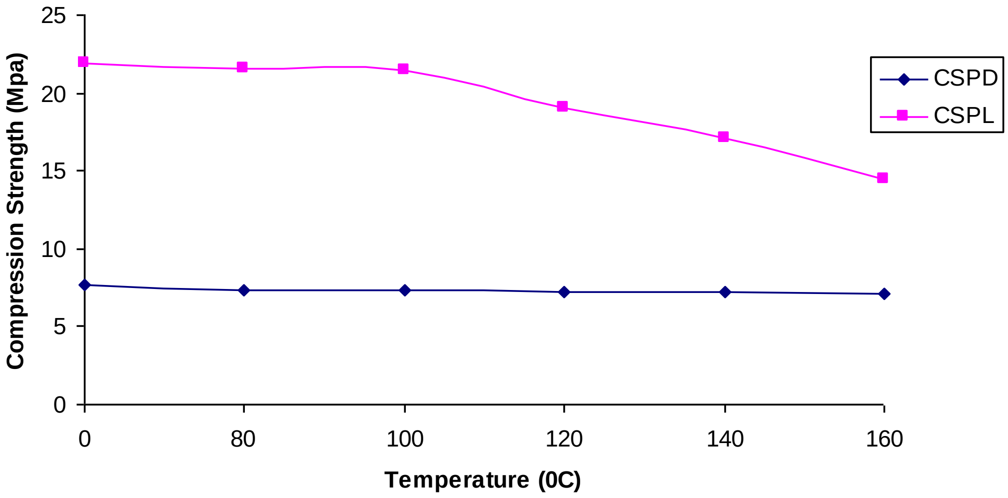

Figure 4.3: variation of CSPD and CSPL with temperature

It is evident from Figure 4.3 above that the greatest change for both compression strength parallel and perpendicular to the grain occur between 0ºC to 80ºC. Subsiquent reduction in compression strength were found to be less than that obtained between 0ºC to 80ºC. when compared with other temperature comditions, heat treated wood samples at a temperature 160ºC gave the lowest values.

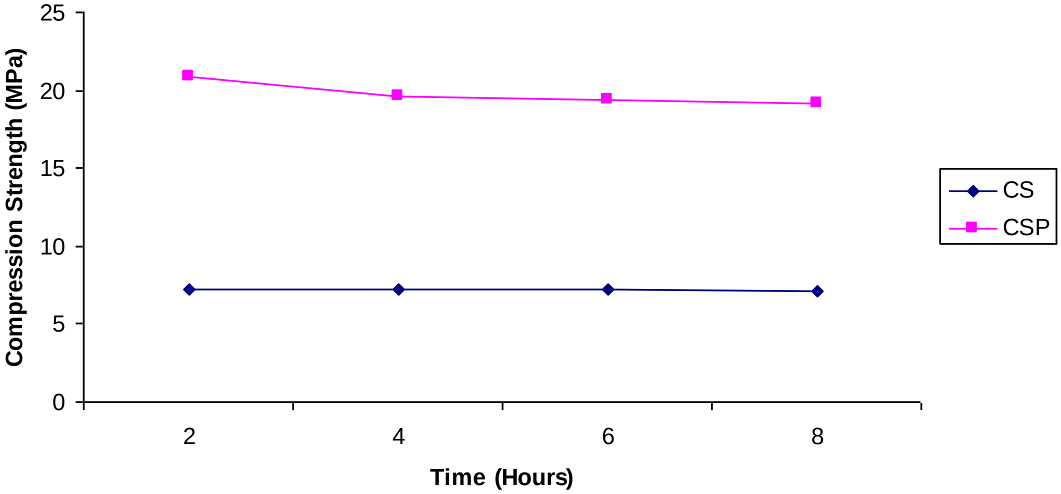

Figure 4.4: The relationship between the Compression Strength Perpendicular and compression strength parallel to the grain of White Afara wood (*Terminalia superba*) and the processing time.

It is evident from Figure 4.4 above that at 2 hours varied time for both compression strength parallel and perpendicular to the grain, White Afara wood (*Terminalia superba*), has its peak. The greatest reduction occurs for compression strength perpendicular to the grain between 4 to 6 hours while subsequent reduction was found to be less than that obtained between 4 to 6 hours. Also, for comprenssion strenght parallel to the grain the greatest reduction occur between 2 to 4 hours while sunsequent reduction was founf to be less than that obtained between 2 to 4 hours. When compared with other time conditions, heat treated wood samples at a time of 8 hours gave the lowest values.

Table 4.7: Density of White Afara wood *(Terminalia superba)* varying temperature at 6 hours

Temperature (^{0}C)	Test 1 (g/cm^3)	Test (g/cm^3)	Test 3 (g/cm^3)	Average (g/cm^3)
Unprocessed	0.66	0.59	0.66	0.64
80	0.66	0.54	0.63	0.61
100	0.63	0.53	0.62	0.60
120	0.56	0.51	0.65	0.57
140	0.59	0.49	0.60	0.56
160	0.51	0.58	0.52	0.54

Table 4.8: Density of White Afara wood *(Terminalia superba)* varying time at 120^{0}C

Time (hours)	Test 1 (g/cm^3)	Test 2 (g/cm^3)	Test 3 (g/cm^3)	Average (g/cm^3)
2	0.63	0.62	0.64	0.63
4	0.58	0.66	0.63	0.62
6	0.60	0.48	0.66	0.58
8	0.58	0.50	0.58	0.55

Total loss compared to the control from table 4.7 above was calculated to be 15.63%. 0.54 grammes per centimetre cube was obtained as the lowest Density value. At $p<0.05$

confidence level, the results presented from ANOVA (Appendix A, Table 6) showed no significance differences. Furthermore, from the relationship between density and processing time (Appendix B, Table 4) showed no significant differences at $p<0.05$ confidence level. Korkut (2009) reported a decreased by 16.12% when compared to the control value in the density of Hornbeam (Carpinus betulus) treated at 180ºC for 6 hours.

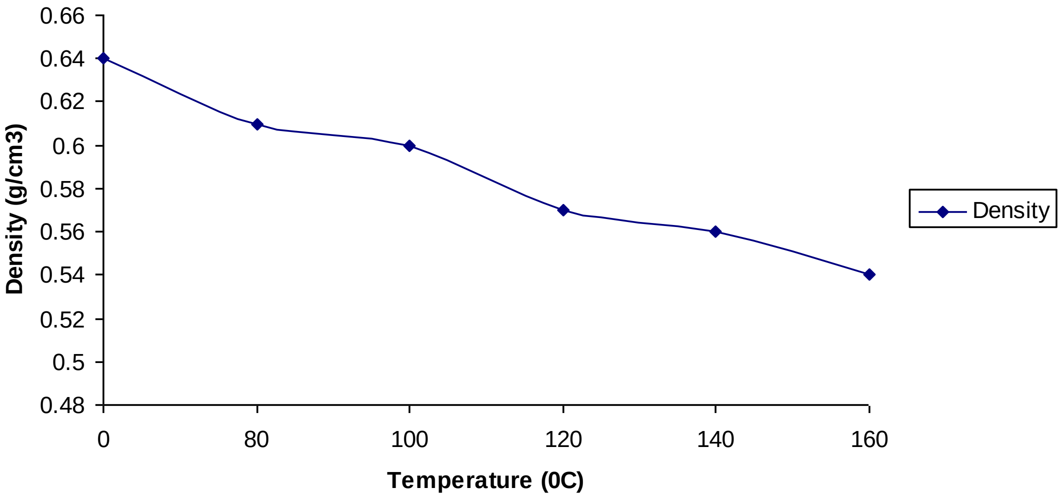

Figure 4.5: The relationship between the Density of White Afara wood (*Terminalia superba*) and the processing temperature.

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Figure 4.5 above depicts that inverse relationship exit between the devity White Afara wood (*Terminalia superba*), and the processing temperature, the greatest reduction in density occurs between 0ºC to 80ºC and 100ºC. the highest density was observed at the unprocessed state.

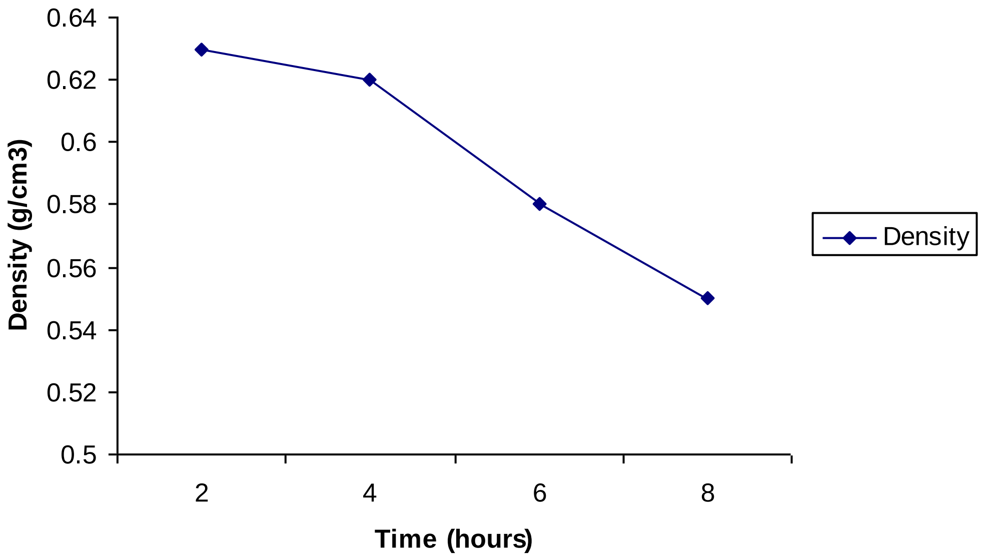

Figure 4.6: The relationship between the Density of White Afara wood (*Terminalia superba*) and the processing time.

From Figure 4.6 above, it is observed that the greatest reduction in density of White Afara wood (*Terminalia superba*) and the processing time occurs between 4 to 6 hours,while susequent reduction was found to be lower than that obtained between 4 to 6 hours. The lowest value obtained for density was observed at 8 hours.

Table 4.9: Radial shrinkage of White Afara wood *(Terminalia superba)* varying temperature at 6 hours

Temperature (^{0}C)	Test 1 (%)	Test 2 (%)	Test 3 (%)	Average (%)
Unprocessed	3.502	3.413	4.031	3.649
80	4.027	3.411	3.499	3.646
100	3.493	3.409	4.024	3.642
120	3.400	4.016	3.482	3.633
140	3.918	3.383	3.463	3.588
160	3.346	3.819	3.267	3.477

Table 4.10: Radial shrinkage of White Afara *(Terminalia superba)* varying time at 120^0C

Time (hours)	Test 1 (%)	Test 2 (%)	Test 3 (%)	Average (%)
2	3.497	3.407	4.026	3.643
4	3.404	3.488	4.023	3.638
6	4.021	3.480	3.395	3.632
8	3.091	3.474	4.012	3.526

From Table 4.9 above, The lowest Radial Shrinkage obtained was 3.477%. 4.71% was the total loss obtained when compared with the unprocessed. No significance was observed from ANOVA (Appendix A, Table 7) at $p< 0.05$ confidence level. Similarly, in the relationship between the radial shrinkage of White Afara wood (*Terminalia superba*),and the processing time no significance difference was obsered at $p<0.05$ confidence level from ANOVA (Appendix B, Table 5). Korkut (2009) reported 54% reduction in Hornbeam (Carpinus betulus) when compared with the control at 180ºC for 6 hours.

Table 4.11: Tangential shrinkage of White Afara wood *(Terminalia superba)* varying temperature at 6 hours

Temperature (^{0}C)	Test 1 (%)	Test 2 (%)	Test 3 (%)	Average (%)
Unprocessed	7.385	6.833	8.071	7.430
80	8.066	6.829	7.383	7.426
100	7.379	6.827	8.063	7.423
120	6.812	8.052	7.366	7.410
140	8.033	6.812	6.984	7.276
160	6.701	7.698	6.543	6.981

Table 4.12: Tangential shrinkage of White Afara wood *(Terminalia superba)* varying time at 120^{0}C

Time (hours)	Test 1 (%)	Test 2 (%)	Test 3 (%)	Average (%)
2	7.019	6.837	8.098	7.318
4	6.812	7.001	8.146	7.320
6	8.046	6.971	6.820	7.279
8	6.193	6.957	8.036	7.062

6.981% was the lowest tangential shrinkage value ontained from Table 4.11 above.Total loss compared to the control was calculated to be 6.04%. at $p<0.05$ confidence level the result presented from ANOVA (Appendix A, Table 8) showed no significant differences. In addition ANOVA (Appendix B, Table 6) frrom the relationship between tangential shrikage of White Afara wood (*Terminalia superba*),and the processing time showed no significant difference. Korkut (2009) reported a degrease up to 55% when compared to the control in the tangential shrinkage of Hornbeam (Carpinus betulus) subjected to heat treatment at 180^{o}C for 6 hours.

Table 4.13: Volumetric Shrinkage of White Afara wood *(Terminalia superba)* varying temperature at 6 hours

Temperature (^{0}C)	Test 1 (%)	Test 2 (%)	Test 3 (%)	Average (%)
Unprocessed	10.887	10.246	12.102	11.078
80	12.093	10.240	10.882	11.072
100	10.872	10.236	12.087	11.065
120	10.212	12.068	10.848	11.043
140	11.951	10.951	10.447	10.864
160	10.047	11.517	9.810	10.458

Table 4.14: Volumetric shrinkage of White Afara wood *(Terminalia superba)* varying time at 120^{0}C.

Time (hours)	Test 1 (%)	Test 2 (%)	Test 3 (%)	Average (%)
2	10.516	10.244	12.124	10.961
4	10.216	10.489	12.169	10.958
6	12.067	10.451	10.215	10.911
8	9.284	10.431	12.048	10.588

From Table 4.13 above, 5.60% was the total loss obtained when the lowest volumetric shrinkage value was compared with the control. Moreso, at $p<0.05$ confidence level no significant deferences was observed betweeen treated and control value. From ANOVA (Appendix A, Table 9). Equally, no significant differnce was obserevd from the relationship between the volumetric shrinkage of White Afara wood (*Terminalia superba*), and the processing time. Korkut (2011) reported a decrease up to 67.47% in the volumetric shrikage of Hornbeam (Carpinus betulus) when subjected to heat treatment for 6 hours at 180ºC.

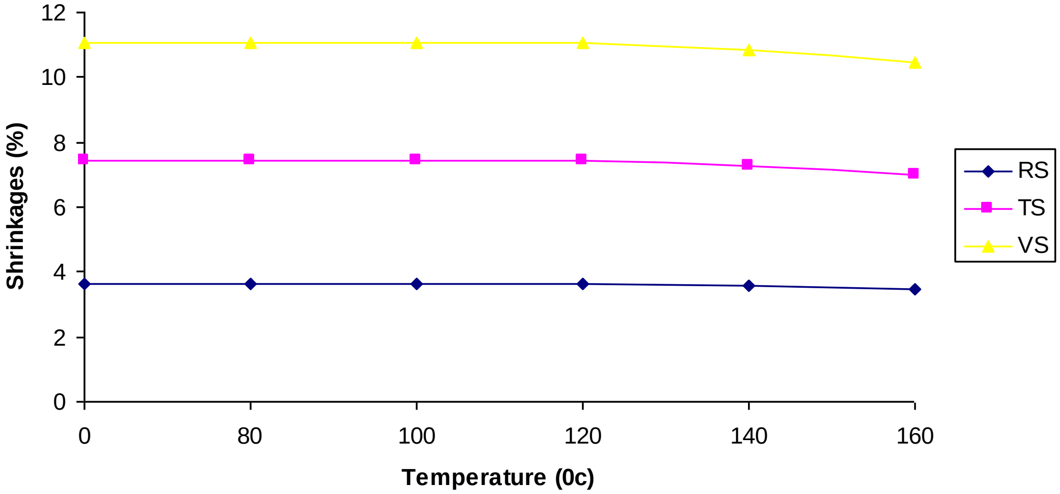

Figure 4.7: The relationship between Radial, Tangential and Volumetric Shrinkages of White Afara wood (*Terminalia Superba*) and the processing temperature

The highest radial, tangential and volumetric shrinkage of White Afara wood (*Terminalia superba*), from Figure 4.7 above was at the control. The greatest reduction occurs between 140ºC to 160ºC all other reductions in volumetric shrinkage was found to be less than that obtained between 140ºC to 160ºC. When compared with other temperature conditions, heat treated samples at 160ºC gave the lowest value.

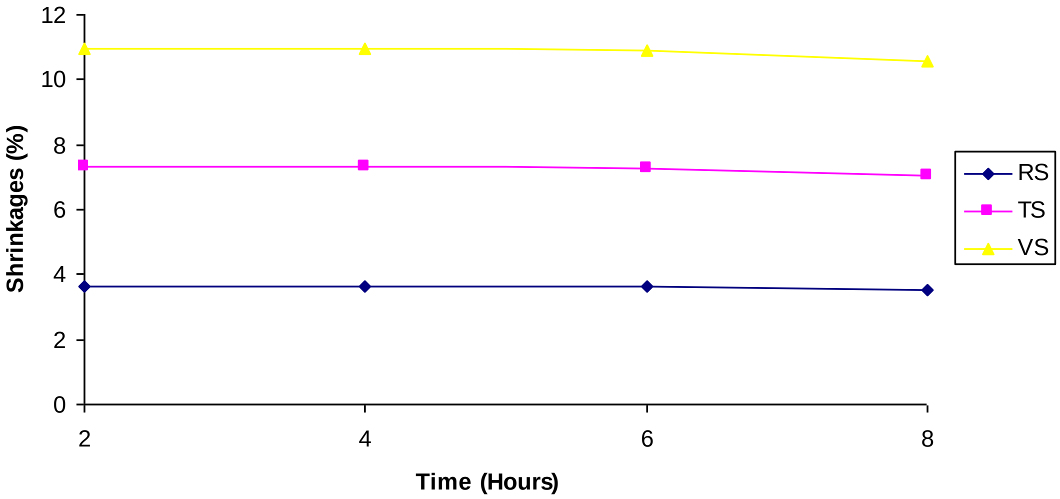

Figure 4.8: The relationship between Radial, Tangential and Volumetric Shrinkages of White Afara wood (*Terminalia Superba*) and the processing time.

From Figure 4.8 above, the highest radial, tangential and volumetric shrinkage was observed at 2 hours. The greatest reduction occurs between 6 to 8 hours while all other reduction in shrinkage was less than that obtained between 6 to 8 hours. Wood samples treated for 8 hours gives the lowest value.

CHAPTER FIVE

5.0 CONCLUSION AND RECOMMENDATIONS

In conclusion, temperature has the greatest influence on White Afara wood (*Terminalia superba*), than time of heat treatment on all the physical properties such as density, moisture content and shrinkage as well as compression strength. The smallest decrease was observed at 80ºC for all the physical properties. In addition, the largest decrease was for moisture content, followed by density and then shrinkage. Similarly the smallest decrease for compression strength was at 80ºC. Given the specific conditions of this research, that is (80,100,120,140 and 160)ºC. It was observed that at 140 and 160ºC splits along the grain was observed as the bound between the grain closes up due to increase in temperature. Total loss in moisture content when compared to the control was 53.29%. Mehmet *et al.*,(2012) reported a decrease up to 8.13% in Oak *(Quarcus petraea)* when compared with the control. The reduction in moisture content of wood is a significant factor in determining the calorific value or the amount of available heat per unit volume of fuel when designing a stove and chimney. Logs that are not properly dried will create lots of smokes and tars. Density and shrinkage of wood affects the proper functioning of acoustical and structural properties of any stringed musical instruments. Wood shrink in proportion to the magnitude of change in its moisture content hence an engineer must ensure an equilibrium in moisture content of wood used in acoustic instrument. Large changes in density and shrinkage can greatly impair and weaken the structure of this instrument. The stresses which act on a wooden material tends to produce a change in its shapes and sizes. Below the fibre saturation point, the compression property of wood varies inversely with moisture content of wood. Above the fibre saturation point the compression property is constant with changes in moisture content. Hence, failure do not greatly affects the compression strength of wood at equilibrium moisture content. Compression property is usually considered when making spindle, roof rafter, chair and table legs. It is recommended that if White Afara wood (*Terminalia superba*), is heat treated at 120ºC, it can be used for window frames, external cladding and garden furniture. Moreso, further research in wood would lead to more efficient utilization of wood in industry and other structural applications.